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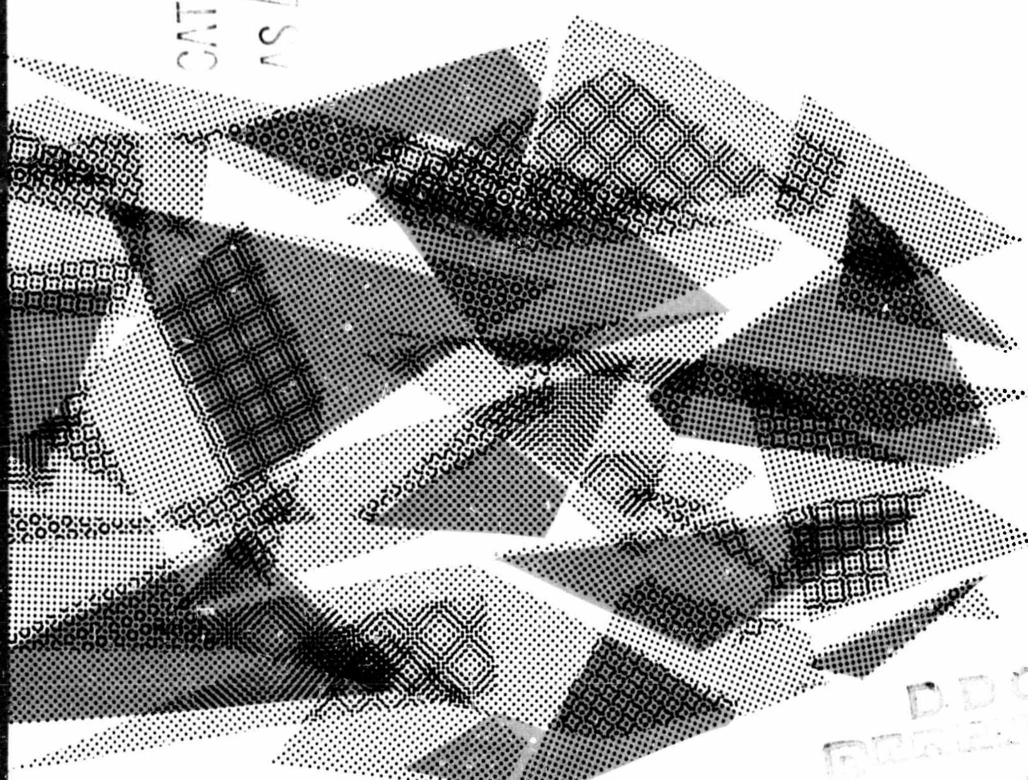
HUNTSVILLE, ALABAMA

SPECIAL REPORT NO. S-85

BALLISTIC CHARACTERISTICS OF NF PROPELLANTS (U)



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ROHM & HAAS COMPANY

REDSTONE ARSENAL RESEARCH DIVISION
HUNTSVILLE, ALABAMA

Report No. S-85

BALLISTIC CHARACTERISTICS OF NF PROPELLANTS

by

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October 5, 1965

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ROHM & HAAS COMPANY

REDSTONE ARSENAL RESEARCH DIVISION
HUNTSVILLE, ALABAMA

BALLISTIC CHARACTERISTICS OF NF PROPELLANTS

ABSTRACT

NFPA/TVOPA propellants having from 1 to 25% aluminum had measured impulse efficiencies of greater than 95%, with densities up to 1.93 gm/cc. Aluminum content had very little effect on burning rate, but higher solids contents caused increased viscosities and higher tensile strengths. The burning rate of RH-SB-103 (15% Al) increased from 0.83 to 1.90 in/sec at 1000 psia as the oxidizer particle size decreased from 180 to 8 microns. The two fastest-burning NF propellants made with 8 and 15μ oxidizer showed no tendency toward transition to higher pressure exponents at pressures up to 5000 psia. The temperature coefficient of RH-SB-103cd was found to be 0.11%/°F over the range from -40 to +140°F.

Liners that had good bonding characteristics, reasonable insulating properties, and that showed promise of good storage life were developed.

Motors containing up to 22 lbm of propellant were fired successfully. The specific impulse measured in a 7-lbm, 6-inch diameter motor was 262.8 lbf-sec/lbm.

Experimental studies showed that NF propellants may be useful in ejector motors for tube-launched missiles.

OPE/NFPA propellants had burning rates up to 3.3 in/sec at 1000 psia and F^0_{1000} values of 260.0 lbf-sec/lbm were obtained from 10-gram micro-motors.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
2. CHARACTERIZATION OF NF PROPELLANT	2
2.1 Effect of Compositional Variations	2
2.2 Effect of Oxidizer Particle Size	7
2.3 Additional Characterization of RH-SB-103cd	10
2.3.1 Reproducibility of Burning Rate and Specific Impulse	11
2.3.2 Measurement of Temperature Coefficient	13
3. LINER DEVELOPMENT	13
3.1 Background	13
3.2 Screening Tests for Prepolymer Propellant	15
3.3 Liner Development for Application Motor	17
3.4 Surveillance Tests of Propellant/Liner Bond	19
4. DEVELOPMENT OF AN APPLICATION MOTOR	19
4.1 Motor Description	20
4.2 Results of Large Motor Firings	20
5. APPLICATION STUDIES IN OTHER MOTORS	20
6. CHARACTERISTICS OF NF PROPELLANTS WITH A HIGHER ENERGY PLASTICIZER	27
6.1 OPE Formulations	27
6.1.1 Burning Rate Behavior	28
6.1.2 Specific Impulse Evaluation	28
7. SUMMARY	33
8. PLANNED EXTENSIONS	35

Appendix A - Liner Bonding Tests

Appendix B - Glossary

Appendix C - Table of Nomenclature

ROHM & HAAS COMPANY

REDSTONE ARSENAL RESEARCH DIVISION
HUNTSVILLE, ALABAMA

BALLISTIC CHARACTERISTICS OF NF PROPELLANTS

1. INTRODUCTION

Until recently the limited availability of ingredients has severely curtailed the ballistic evaluation of NF propellants. A few exploratory firings in 0.75-inch micro-motors showed that very high rates could be achieved[1] but there were no materials available for the large number of tests needed to define the limits of burning rate, determine the effect of aluminum content on specific impulse, measure π_K and other important parameters, and to develop liner materials.

A substantial increase in raw material capacity made possible a greatly expanded ballistic evaluation effort in 2-inch and 6-inch test hardware and this interim report gives the up-to-date results of this work. The propellant binder used was a 2:1 mixture of 2, 3 bis (difluoramino)propyl acrylate (NFPA), copolymerized with a small amount of hydroxypropyl methacrylate to form a prepolymer, and 1, 2, 3 tris (1, 2 bis [difluoramino] ethoxy)propane (TVOPA) plasticizer. Hexamethylene diisocyanate was the binder crosslinker and aluminum and ammonium perchlorate comprised the remainder of the propellant.

Preliminary results are reported for a limited evaluation of NF propellants containing the higher-energy plasticizer 1, 2, 2, 5, 6, 9, 9, 10-octakis(difluoramino)-4, 7 dioxadecane (OPE).

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[1]Rohm & Haas Company, "Ballistic Evaluation of High-Burning-Rate NF Propellants," Special Report S-63, May 1965.

2. CHARACTERIZATION OF NF PROPELLANT

2.1 Effect of Compositional Variations

A series of propellants with aluminum content ranging from 1 to 25% by weight was formulated to explore the possible effects on burning rate and specific impulse. Calculations were made to assure that the propellants would be near the maximum specific impulse for each aluminum level. The total solids content was increased as aluminum content exceeded 15% to maintain the oxidation balance.

The maximum calculated specific impulse occurred near 15 weight percent aluminum, but the values at 1% and 25% remained above the 264 lbf-sec/lbm (Fig. 1). The theoretical density and volumetric impulse of those propellants having higher aluminum contents were attractive; the density of the 25% composition exceeded 1.9 gm/cc (Table I).

Compositions RH-SB-184 and -188 were not exactly at the optimum oxidizer/binder ratio, but the calculated specific impulse values were within 0.2% of the maximum. Since preliminary processing work had already been done with -184 by the time the results of the calculations were received, the composition was not adjusted. Composition -188, at 30% binder, had very high viscosity; the optimum 25% aluminum formulation would have had only 27% binder and a still higher viscosity, and was therefore not attempted.

These propellants showed the expected trends in processing viscosity and mechanical properties; as the total solids content increased, the viscosity and tensile strength also increased while the elongation decreased. The 8.0 kilopoise viscosity of RH-SB-188 was the highest encountered thus far with NF propellants (Table II).

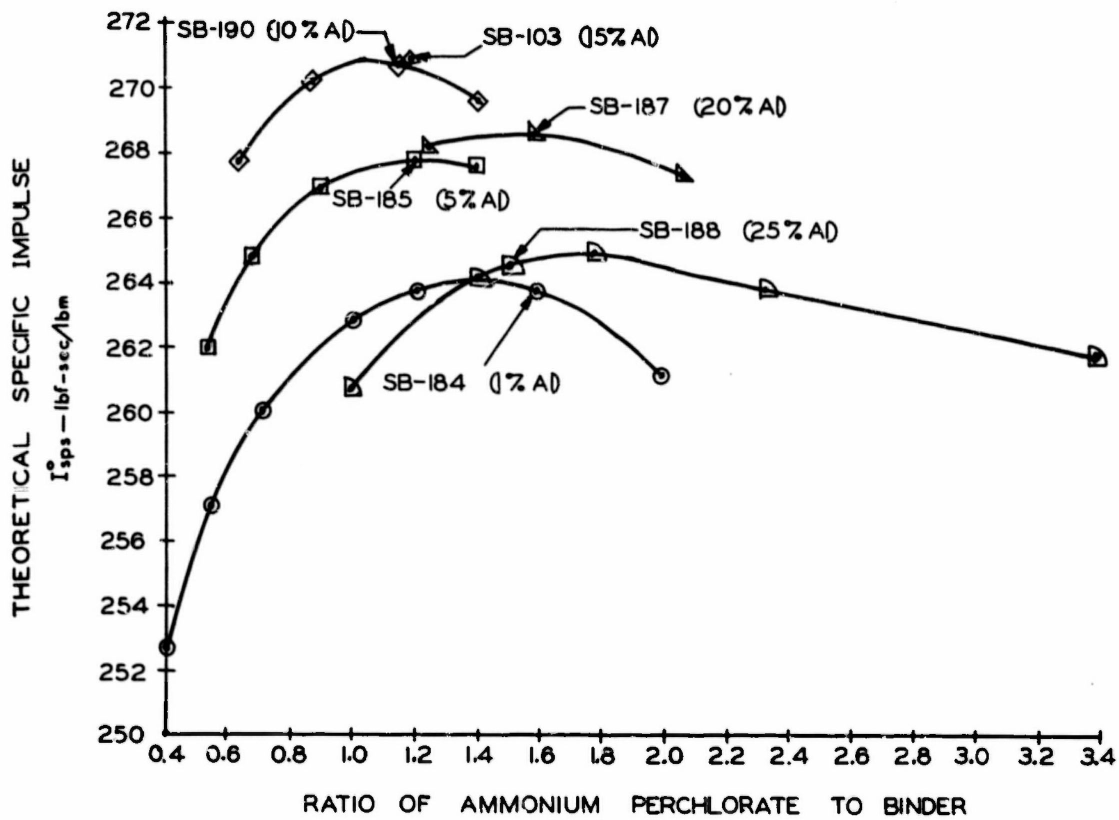


FIG. 1 EFFECT OF AMMONIUM PERCHLORATE TO BINDER RATIO AND ALUMINUM CONTENT ON THEORETICAL SPECIFIC IMPULSE.

Table I

Compositions and Theoretical Properties of Propellants in a Study of the Effect of Aluminum Content

Parameter	SB-184	SB-185	SB-190	SB-103	SB-187	SB-188
Composition						
NFPA	12.7	14.4	14.0	13.0	10.3	10.0
TVOPA	25.4	28.8	28.0	26.0	20.6	20.0
Ammonium Perchlorate	60.9	51.8	48.0	39.0	49.1	45.0
Aluminum	1.0	5.0	10.0	15.0	20.0	25.0
I^0_{sps}, lbf-sec/lbm	263.8	267.8	270.8	270.8	268.6	264.7
Chamber Temperature, °K	3289	3423	3554	3666	3843	3900
Density, lbm/in³	0.064	0.064	0.065	0.066	0.069	0.070
Density, gm/cc	1.77	1.77	1.80	1.84	1.90	1.93
$\rho \cdot I^0_{sps}$, lbf-sec/in³	16.88	17.14	17.60	17.87	18.53	18.53
Ratio of Oxidizer to Binder	1.60	1.20	1.14	1.18	1.59	1.50

Table II

Viscosity and Mechanical Properties of Propellants

Designation	Aluminum Content (%)	Total Solids (%)	Viscosity (kpoise at 100° F)	Tensile Strength (psi)	Elongation (in/in)
RH-SB-184	1	61.9	2.2	29	0.16
RH-SB-185	5	56.8	1.1	26	0.24
RH-SB-190	10	58.0	1.2	28	0.26
RH-SB-103	15	61.0	2.0	26	0.30
RH-SB-187	20	69.1	5.6	54	0.13
RH-SB-188	25	70.0	8.0	64	0.15

The propellants were test-fired in 2C1.5-4.0 motors[1] to determine the effect of aluminum content on the specific impulse efficiency, the burning rate, and the pressure exponent. Four rounds were fired with each propellant to determine the P-K-r relationships. Changing the aluminum content caused little variation in the burning rate behavior of the propellants, although a small decrease in pressure exponent at the higher aluminum levels was noted (Fig. 2, Table III).

[1]The 2C1.5-4.0 motor has a case I.D. of 2.0 in., a cylindrical grain design, a grain I.D. of 1.5 in., and a motor case length of 4.0 inch.

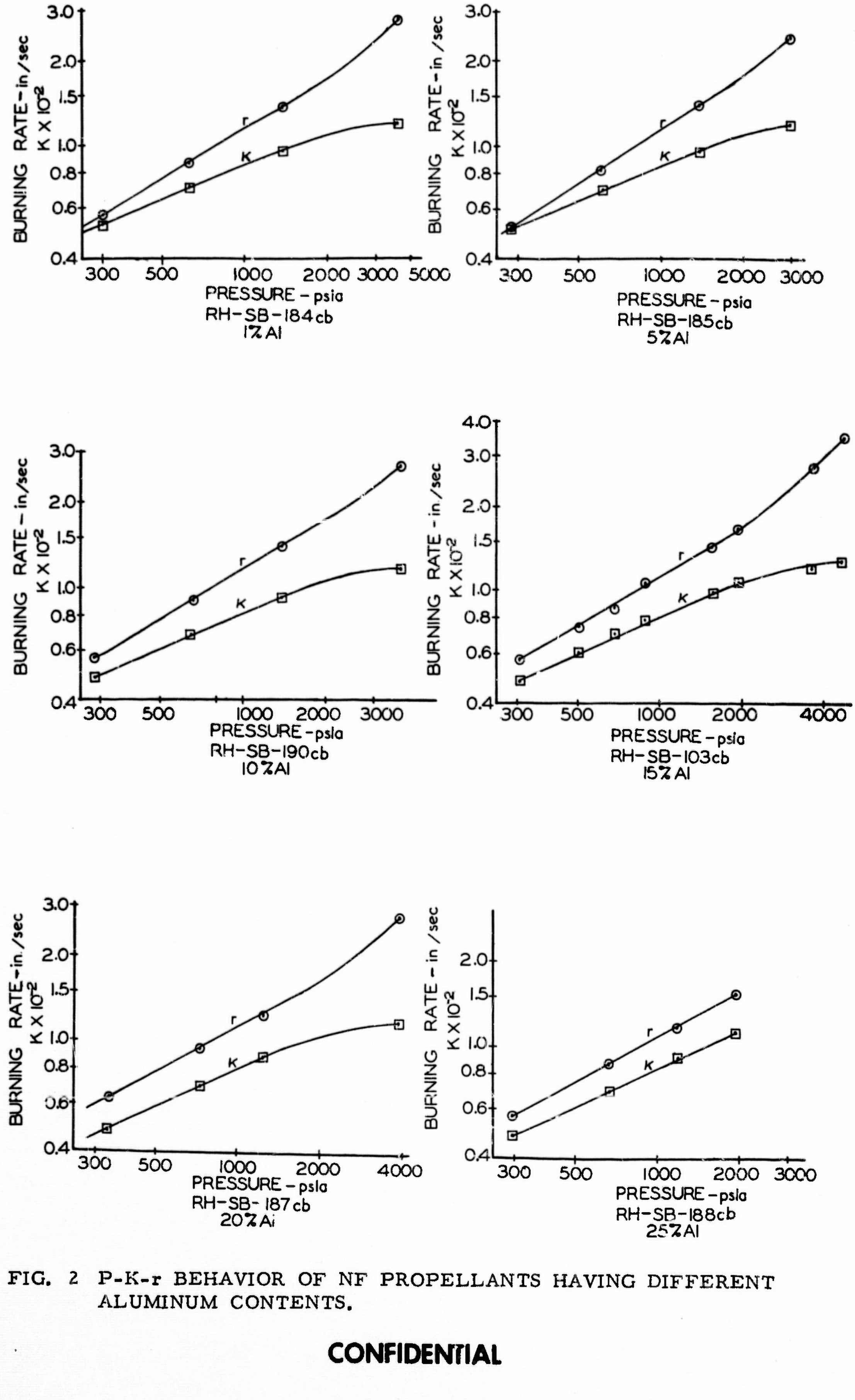


FIG. 2 P-K-r BEHAVIOR OF NF PROPELLANTS HAVING DIFFERENT ALUMINUM CONTENTS.

Table III

Effect of Aluminum Content on Burning Rate

Propellant	Aluminum Content (wt. %)	Burning Rate @ 1000 psia (in/sec)	Pressure Exponent @ 1000 psia
RH-SB-184	1	1.16	0.60
RH-SB-185	5	1.16	0.63
RH-SB-190	10	1.15	0.60
RH-SB-103	15	1.14	0.56
RH-SB-187	20	1.15	0.53
RH-SB-188	25	1.10	0.54

The specific impulse efficiency of the NF propellants measured in the 2C1.5-4 configuration remained high, even at the 25% aluminum level (Table IV). It is estimated that each of the propellant compositions would deliver at least 97% of theoretical specific impulse in a 100 lbm motor (9C6.3-30). The high-aluminum propellants should be attractive in volume-limited systems.

Table IV

Effect of Aluminum Content on Ratio of F^0_{1000} to I^0_{sps}

Propellant	Aluminum Content (wt. %)	I^0_{sps} (lbf-sec/lbm)	F^0_{1000} [a] (lbf-sec/lbm)	Ratio F^0_{1000}/I^0_{sps}
RH-SB-184	1	263.8	252.8	0.958
RH-SB-185	5	267.8	254.6	0.951
RH-SB-190	10	270.8	256.0	0.945
RH-SB-103	15	270.8	257.0	0.949
RH-SB-187	20	268.6	254.0	0.946
RH-SB-188	25	264.7	249.7	0.943

[a] Each number is the average of 4 values measured in 2C1.5-4.0 motors containing about 0.35 lbm propellant.

2.2 Effect of Oxidizer Particle Size

The effect of different ammonium perchlorate particle sizes on processing and mechanical properties was determined for RH-SB-103, since it was the candidate propellant for scale-up. The processing viscosity and tensile strength increased with decreasing particle size, while the elongation remained virtually constant except with 8μ oxidizer (Table V, Fig. 3).

Table V

Effect of Ammonium Perchlorate Size on Viscosity and Mechanical Properties

D_M^{50}	Viscosity (kpoise @ 100°F)	Tensile Strength (psi)	Elongation (in/in)
8	2.8	48	0.33
15	3.1	52	0.21
43	2.1	50	0.19
55	0.9	32	0.20
100	0.8	36	0.20
180	0.5	20	0.18

The oxidizer particle size had a strong effect on the burning rate of RH-SB-103 and on its pressure exponent above 2000 psia. Eight each 2C1.5-4.0 motors were made with propellant having oxidizer with nominal D_M^{50} values of 8, 15, 43, 55, 100, and 180 microns. All motors were conditioned to +77 ± 2°F for at least 24 hours before firing.

The data were very consistent over the pressure range of 300 to 5000 psia. The burning rate increased from 0.83 to 1.90 in/sec at 1000 psia as the particle size was decreased from 180 to 8 microns; the pressure exponent at 1000 psia was constant (Fig. 4, Table VI). However, propellant made with large particle oxidizer ($D_M^{50} > 43\mu$) showed a well-defined change in pressure exponent or break-point in the neighborhood of 1500 to 2000 psia.

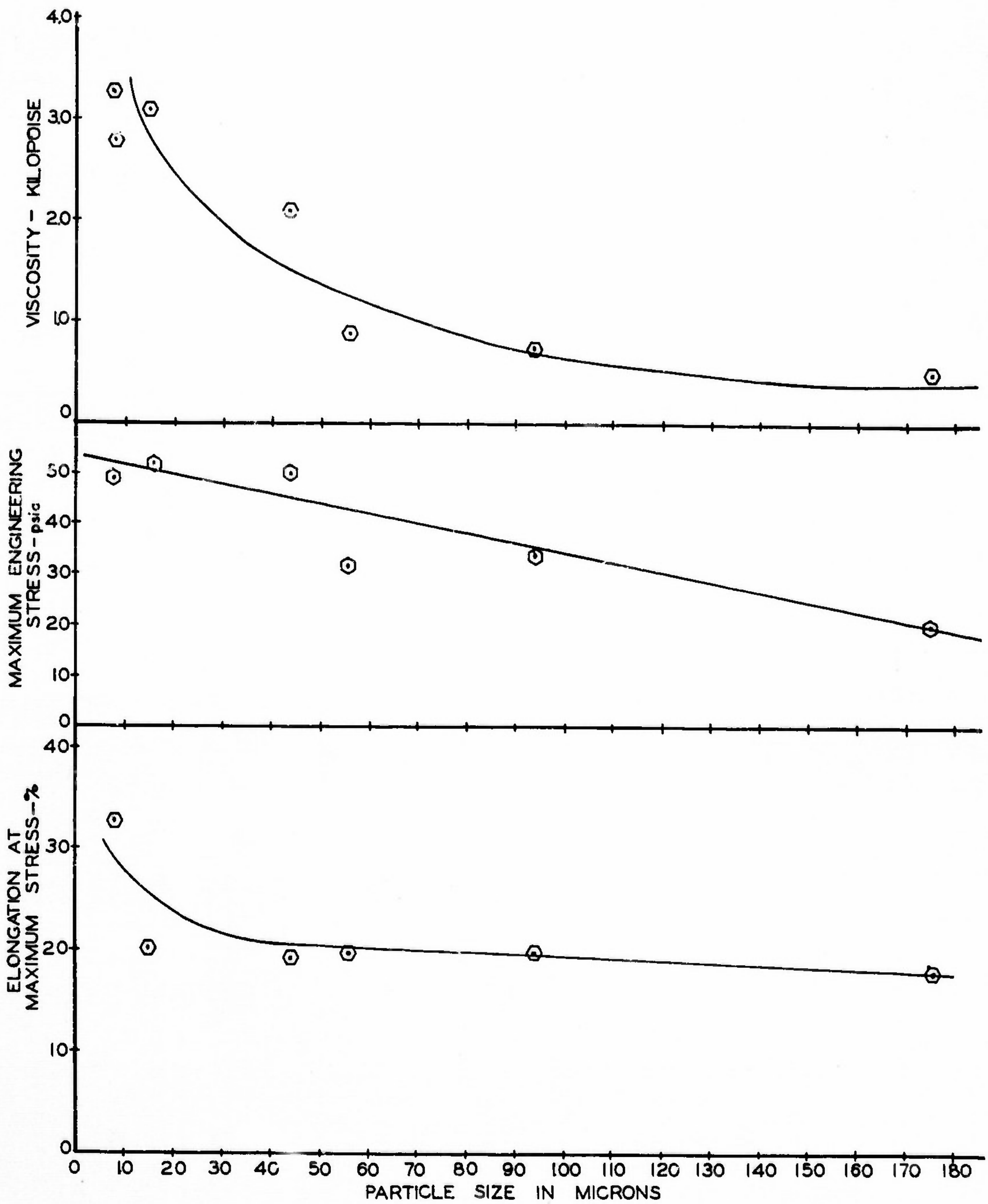


FIG. 3 EFFECT OF OXIDIZER PARTICLE SIZE ON VISCOSITY AND MECHANICAL PROPERTIES OF RH-SB-103 PROPELLANT.

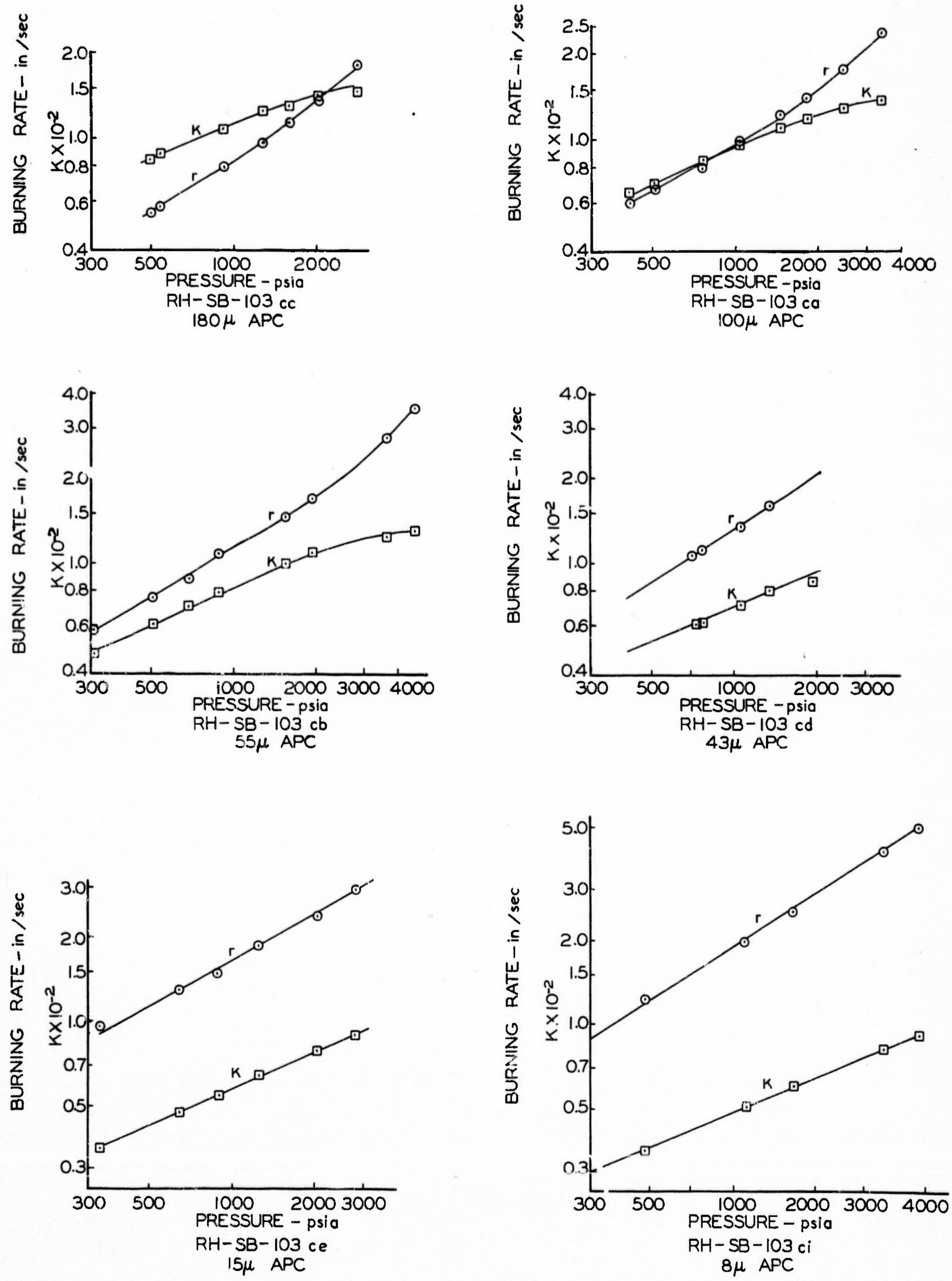


FIG. 4 EFFECT OF OXIDIZER P'RTICLE SIZE ON BURNING RATE AND PRESSURE EXPONENT O. RH-SB-103 PROPELLANT.

Table VI

Effect of Ammonium Perchlorate Size on Burning Rate and Pressure Exponent

D^{50}_{M}	Burning Rate @ 1000 psia (in/sec)	Pressure Exponent @ 1000 psia	Pressure Exponent @ 2000 psia
8	1.90	0.62	0.62
15	1.65	0.56	0.56
43	1.30	0.56	0.60
55	1.15	0.56	0.66
100	0.97	0.56	0.73
180	0.83	0.60	0.75

The tendency of the pressure exponent to increase in the neighborhood of 1500-2000 psia was absent for an oxidizer particle size below 15μ(Fig. 5). The absence of a break-point in an NF system was first discovered in a propellant having a 3/1 ratio of TVOPA/NFPA and containing 8μ oxidizer,[1] but it applies to the 2/1 ratio and 15μ oxidizer as well. For propellants containing ammonium perchlorate, this property is unique to the NF binder system. It indicates that there is no practical upper limit on the operating pressure of a motor containing RH-SB-103ci or a similar propellant.

2.3 Additional Characterization of RH-SB-103cd

This propellant was selected for use in the 20-lbm Application Motor because of its good processing and high burning rate characteristics. Additional data on ballistic reproducibility and temperature coefficient were obtained to supplement the proposed firings.

[1]Rohm & Haas Company, "Ballistic Evaluation of High-Burning-Rate NF Propellants,"(U) Special Report S-63, May 1965.

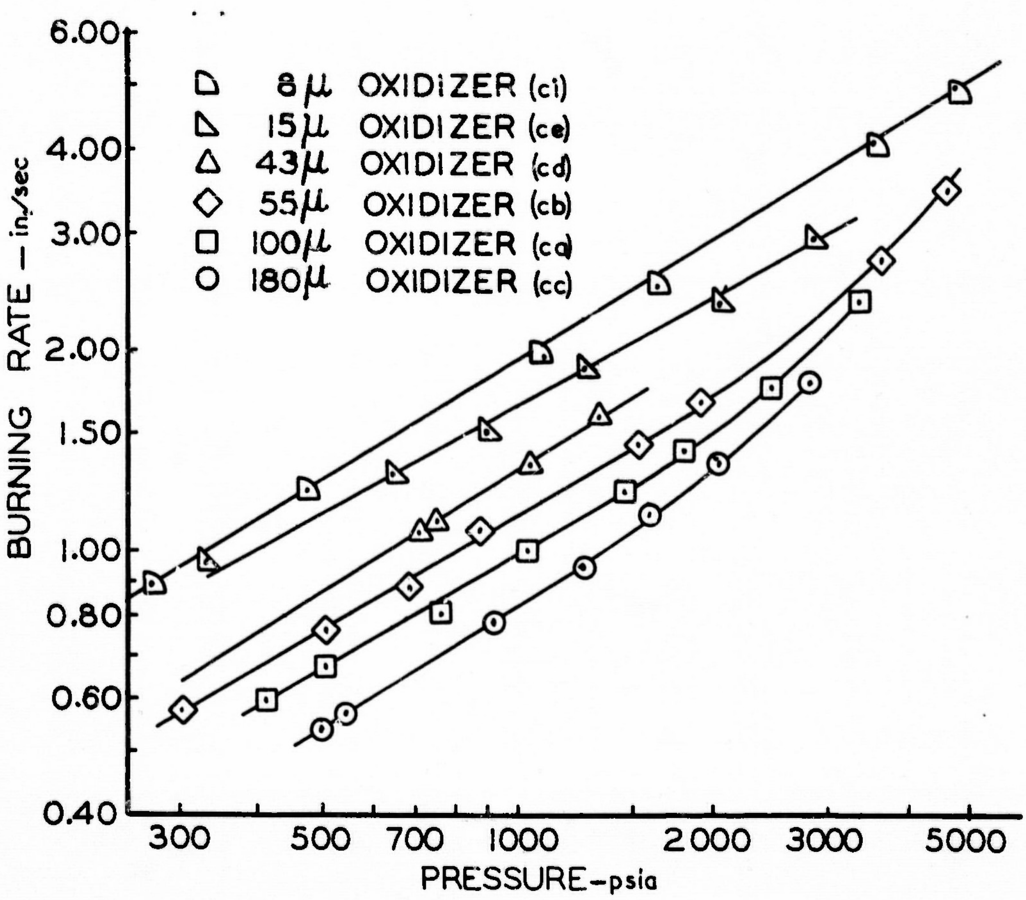


FIG. 5 BURNING RATE-PRESSURE BEHAVIOR FOR RH-SB-103 PROPELLANT CONTAINING VARIOUS OXIDIZER SIZES.

2.3.1 Reproducibility of Burning Rate and Specific Impulse

Over 30 clamp-type 2C1.5-4.0 motors representing 8 batches were fired to assure that the propellant was ballistically reproducible before the large motors were cast. The results were good; for 20 motors fired at a K_m of 70 ± 2 the standard deviations of burning rate and specific impulse were 2.4% and 0.4%, respectively (Table VII).

Table VII

Results of Reproducibility Firings for RH-SB-103cd

Purpose	Batch No.	Round No.	K_m	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	I_{spd} (lbf-sec/lbm)	F^0_{1000} (lbf-sec/lbm)
P-K-r	1031	4200	64	726	1.03	245.6	258.1
		4201	75	1177	1.46	258.4	261.2
		4203	93	1564	1.66	259.5	258.6
		4202	75	974	1.14	253.4	259.0
P-K-r	1032	4205	62	742	1.11	247.3	259.5
		4206	72	1047	1.36	255.9	260.5
		4204	79	1287	1.39	259.2	261.0
P-K-r	1033	4207	62	735	1.10	246.9	258.9
		4210	80	1343	1.61	258.1	259.2
		4209	71	988	1.24	255.6	260.9
		4208	71	1037	1.33	255.8	260.8
Specific Impulse	1034	4242	71	981	1.27	253.3	259.3
		4243	72	1009	1.27	255.0	259.9
		4244	69	927	1.25	252.4	259.6
		4245	68	938	1.22	252.9	259.4
		Ave.	70	964	1.25		259.6
Specific Impulse	1040	4336	70	933	1.20	252.8	259.4
		4337	70	890	1.20	251.3	258.9
		4338	70	905	1.20	251.4	258.8
		4339	69	884	1.21	250.8	258.6
		Ave.	70	903	1.20		258.9
Specific Impulse	1053	4384	70	976	1.27	253.4	258.8
		4385[a]	59	710	1.09	244.3	256.8
		4386[a]	61	760	1.13	246.1	256.9
		4387	71	907	1.20	252.0	258.9
		4388	69	920	1.21	252.4	258.9
		4389	71	935	1.22	252.2	258.5
		4390	71	944	1.23	253.3	259.3
		Ave.	71	936	1.23		258.9
Specific Impulse	1058	4406	70	957	1.27	251.4	257.9
		4407	71	935	1.24	252.2	258.8
		4408	69	908	1.21	248.0	255.3
		4409	68	920	1.23	251.8	258.5
		Ave.	70	930	1.24		257.6
Specific Impulse	1062	4424	70	903	1.19	253.6	260.5
		4425	69	939	1.28	252.4	259.2
		4426	68	876	1.20	252.9	260.5
		Ave.	69	906	1.22		260.1
Overall Average			70	929	1.23		259.0
		σ	1.0	33	0.03		1.1
		σ%	1.6	3.5	2.4		0.4

[a] Left out of averages; fired at low K_m.

2.3.2 Measurement of Temperature Coefficient

A total of 26 motors containing RH-SB-103cd were fired at temperatures ranging from -40 to +140° F. All motors were insulated in boxes made of polystyrene foam and were conditioned at least 24 hours before firing; all were fired within 3 minutes of removal from temperature conditioning. Thermocouple measurements using an inert grain showed that this treatment of the rounds was adequate. The motor reached thermal equilibrium with its surroundings within 15 hours after being placed in conditioning, while three minutes after removal to ambient conditions the grain temperature had changed by less than one degree. The data obtained were quite reproducible (Table VIII).

The pressures and rates corrected to $K_m = 71$ were used to calculate π_K, which over the range from -40 to +140° F was 0.11%/° F. Plotting the data as log $\overline{P}_b$ and log $\overline{r}_b$ versus T showed that the temperature sensitivity was not a function of temperature; the data fell along a straight line (Fig. 6).

This value of π_K compares favorably with that of most inert binder composite propellants. The effects of oxidizer particle size and different TVOPA/NFPA ratios were not determined. However, π_K would probably not be affected by particle size because the exponent at 1000 psia is not sensitive to that parameter. There are indications that the TVOPA to NFPA ratio could have a greater effect because other work demonstrated that this ratio does affect the pressure exponent.

3. LINER DEVELOPMENT

3.1 Background

The initial work with NF propellants was based on a binder system of NFPA monomer cured with a peroxide. Since the propellant plasticizer (TVOPA) was in short supply, tests were made

Table VIII

Temperature Coefficient Data for RH-SB-103cd

Round No.	T, °F	K_m	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	Average Values Corrected to $K_m = 71$: $\overline{P}_b$ (psia)	Average Values Corrected to $K_m = 71$: $\overline{r}_b$ (in/sec)
4579	-43	70.8	699	0.936		
4575		71.5	687	0.936		
4576		70.5	700	0.952		
4577		70.3	671	0.889		
4571		70.7	681	0.897		
Average		70.8	687	0.922	691	0.925
4572	+8	72.0	769	0.995		
4574		70.6	767	0.995		
4573		70.5	742	0.978		
4570		70.5	752	0.980		
4571		71.4	790	1.034		
Average		71.0	764	0.996	764	0.996
4586	+52	70.6	794	1.019		
4587		70.7	797	1.023		
4588		70.4	778	1.025		
4589		70.3	769	1.068		
4590		70.4	779	1.017		
Average		70.5	783	1.030	796	1.047
4568	+79	70.2	816	1.076		
4569		71.8	856	1.113		
Average		71.0	836	1.094	836	1.094
4596	+96	70.3	820	1.097		
4595		70.4	819	1.093		
4594		70.3	832	1.083		
4593		70.5	818	1.070		
4592		70.6	824	1.081		
Average		70.4	823	1.085	839	1.116
4597	+144	70.6	882	1.166		
4598		71.5	884	1.172		
4600		70.9	898	1.193		
4601		70.5	852	1.126		
Average		70.9	879	1.164	882	1.167

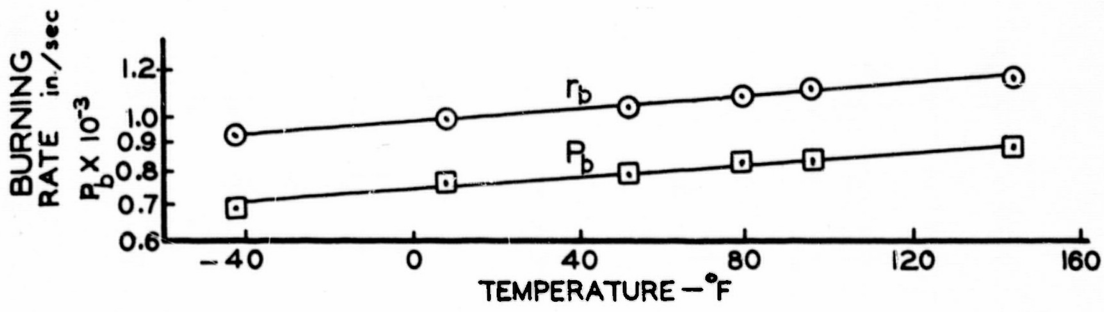


FIG. 6 EFFECT OF TEMPERATURE ON BURNING RATE AND BURNING PRESSURE OF RH-SB-103cd.

to show that an inert plasticizer (Santicizer®[1]-160) could be substituted without grossly affecting the bonding characteristics of the propellant. Screening tests showed that polyester/asbestos and phenolic/asbestos liners were satisfactory, that the propellant bonded well to bare steel, and that substituting Santicizer®[1]-160 for TVOPA did not seriously affect the bonding characteristics.

3.2 Screening Tests for Prepolymer Propellant

The propellants discussed in this report were based on the NFPA/HPMA prepolymer cross-linked with hexamethylene diisocyanate. Since this cure mechanism involved a different chemical reaction than with the monomer system, the liner screening tests were rerun. The propellant plasticizer was still Santicizer®[1]-160. The liner materials which gave the bests results in previous tests and several polyurethane materials were tested with this prepolymer system for initial bondability. The polyester/asbestos, phenolic/asbestos, and bare steel gave excellent bonding results (Table IX). Essentially no propellant bonds were obtained with the polyurethane materials. Appendix A describes the test methods used.

---

[1]Trademark for a line of resin plasticizers, Monsanto Chemical Co., St. Louis 66, Missouri.

Table IX

Bond Test Results of Prepolymer NF Propellant Containing Santicizer-160 to Various Materials

Material Designation[a]	Description	Average Pull Strength (psig)	Type Failure
PL-1	Cellulose Acetate	29[b]	Cohesive propellant/ propellant bond.
E-55	Epoxy	30[b]	Cohesive propellant. Low peel resistance.
E-53-L	Epoxy	26[b]	Cohesive propellant. Low peel resistance.
42RPD	Phenolic/asbestos	28[c]	Cohesive propellant. Good peel resistance.
P-43	Polyester	18[c]	Cohesive liner. Polyester was weakened by propellant.
LR6-73	Polyester/asbestos	30[c]	Cohesive propellant. Good peel resistance.
A-L-100	Polyurethane	0[b]	Propellant bond.
D-65	Polyurethane	31[b]	Cohesive propellant/ propellant bond. Low peel resistance.
D-65-A	Polyurethane primer	0[b]	Propellant bond.
D-904	Polyurethane	0[b]	Propellant bond.
F-700	Polyurethane	0[b]	Propellant bond.
Mild Steel	Zinc phosphate coated	28[c]	Cohesive propellant. Good peel resistance.
Stainless Steel	Rough surface	27[b]	Cohesive propellant. Good peel resistance.

[a] A glossary of designations is presented in Appendix B.
[b] The average of two samples tested at +77° F.
[c] The average of four samples tested at +77° F.

3.3 Liner Development for Application Motor

The slotted-tube grain design for the application motor required a liner that was a reasonably good insulator. The trowelable LR6-73 and bag-molded 42-RPD were selected for further testing on the basis of the screening results and the good experience in handling these materials. The initial bond of propellant to both materials was evaluated with a large number of samples using propellant with the "live" plasticizer, TVOPA. All samples showed good initial bonding with cohesive propellant breaks being obtained (Table X). LR6-73 (Table XI) was selected as the primary liner material for the first series of application motors because it was easier to apply than 42-RPD.

Table X

Reproducibility of Initial RH-SB-103 Propellant Bond to Selected Liners

Liner	No. Samples	Average Pull Strength (psig)	Type Failure
42 RPD	12	25	Cohesive propellant. Good peel resistance.
LR6-73	12	32	Cohesive propellant. Good peel resistance.

Table XI

LR6-73 Liner Formulation

Component	Wt. %
Paraplex® P-13	35
Paraplex® P-43	35
7TF-1 Asbestos[a]	30
Lupersol DDM[b] (Curing Agent)	1% added

[a] Johns-Manville, New York.
[b] Wallace and Tiernan Corp., Newark, N. J.

In an effort to accumulate a background of data on the reproducibility of this propellant/liner system, several bond jigs were filled from each propellant batch manufactured in the program to characterize RH-SB-103cd. Eight batches of bond jigs were cast; in some tests no propellant bond was obtained while in others excellent bonds were formed. In all cases the propellant quality appeared to be good. A review of the liner preparation process and propellant processing data indicated an effect of liner cure time on the propellant bond (Table XII).

Table XII

Propellant Bond Results with LR6-73 Liner

Propellant Batch No.	Cure History of Liner	Bonding Results
1016	Several days cure at +110° F	No good.
1018	Approximately 24 hours at +140° F	Fair bond initially, bond weakened severely after one week.
1023	Approximately 20 hours at +140° F	No good.
1030	Approximately 20 hours at +140° F	No good.
1031	Approximately 20 hours at +140° F	No good.
1032	Approximately 20 hours at +140° F	No good.
1033	One hour at +150° F plus one hour at +70° F	Good bond.
1037	Two hours at +140° F	Good bond.

A test was made to determine if this effect could be demonstrated in a controlled experiment using one batch each of liner and propellant. The previous indications were substantiated in this test. Liner cure times of as long as 24 hours resulted in no propellant bond being formed while shorter cure times of 0 to 6 hours gave excellent bonding results (Table XIII). The short cure time was successfully used in application motor processing.

Table XIII

Effect of Cure Time of LR6-73 on Propellant Bond

No. Samples	Cure Time of Liner (hours at +140° F)	Average Pull Strength (psig)	Type Failure
5	>100	0	Propellant bond.
10	24	0	Propellant bond.
6	6	46	Cohesive propellant.
6	4	48	Cohesive propellant.
6	2	38	Cohesive propellant.
6	0	40	Cohesive propellant.

3.4 Surveillance Tests of Propellant/Liner Bond

A surveillance test at +140° F was initiated with LR6-73 liner to determine propellant bond integrity as a function of time. The test consisted of fifty-six bond jigs with two samples being tested daily during the first several days. After about two weeks it appeared that the propellant bond was showing no indication of immediate deterioration. The testing intervals were, therefore, extended over 100 days with no signs of bond failure being observed. The average pull strength of all samples tested was 45 psig with a standard deviation of 6 psig.

4. DEVELOPMENT OF AN APPLICATION MOTOR

Six-inch motor hardware has been designed and fabricated to serve as a demonstration unit for NF propellants. The configuration uses a slotted tube grain to give a reasonable loading fraction (0.75), a neutral trace, and sharp end of burning. This motor will provide experience with processing and quality control, data on integrity of propellant and liner at temperature extremes and under cycling conditions, data on ballistic reproducibility, and information on surveillance storage behavior.

4.1 Motor Description

A previous report[1] describes the design of the Application Motor in detail; briefly it is a 6-inch I.D., 18-inch long motor with a domed head-end and a slotted-tube grain (Fig. 7). Pertinent physical dimensions are presented in Table XIV.

4.2 Results of Large Motor Firings

Two 6ST18 motors were manufactured using RH-SB-103cd and one was made with RH-P-112cb for comparison purposes. The liner used with the NF motors was LR6-73. The 22 lbm NF grains were substantially perfect castings which fired successfully; in each case ignition was smooth and the shape of the pressure trace was good (Fig. 8). The F^0_{1000} value obtained from these firings was 257.9 lbf-sec/lbm (Table XV).

The corrected specific impulse obtained was disappointing, since a motor this large had been expected to yield an F^0_{1000} of over 260 lbf-sec/lbm. However, a comparison of specific impulse measurements from 6C5-11.4 motors and from 6ST18 motors using both RH-P-112 and RH-SB-103 propellants showed that the larger, 20 lbm-class 6ST18 yielded lower values (Table XVI).

The most reasonable explanation of this effect is that the heat transfer in the slotted area is very high and the heat lost in that area reduces the total available energy. This point is currently being investigated more extensively.

5. APPLICATION STUDIES IN OTHER MOTORS

One of the interesting potential uses for NF propellants is in the high pressure, short-duration, high-thrust motors used to eject tube-launched missiles.[1] In addition to the obvious

[1]Rohm & Haas Company, "Application of NF Propellants—A Study Report," (U), Special Report S-62, May 25, 1965.

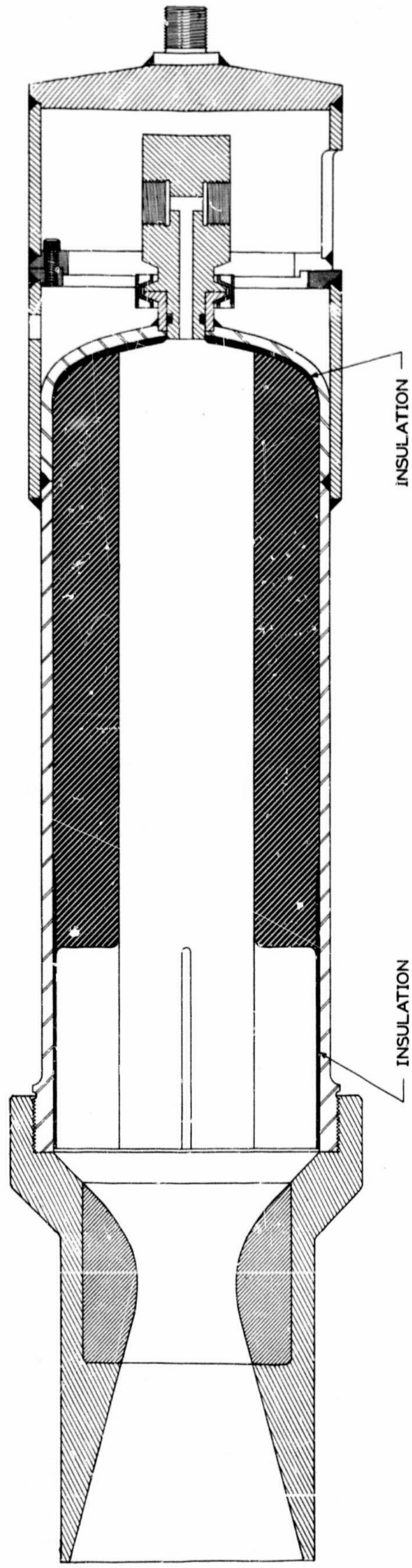


FIG. 7 APPLICATION MOTOR FOR NF PROPELLANT EVALUATION.

Table XIV

Parameters of Application Motor with ST Configuration

Grain Length, in.	18.0
Outside Diameter of Grain, in.	6.0
Inside Diameter of Grain, in.	3.0
Number of Slots	4
Length of Slots, in.	4.46
Web, in.	1.5
Loading Fraction, ϵ	0.73
Reduced Web, w*	0.25

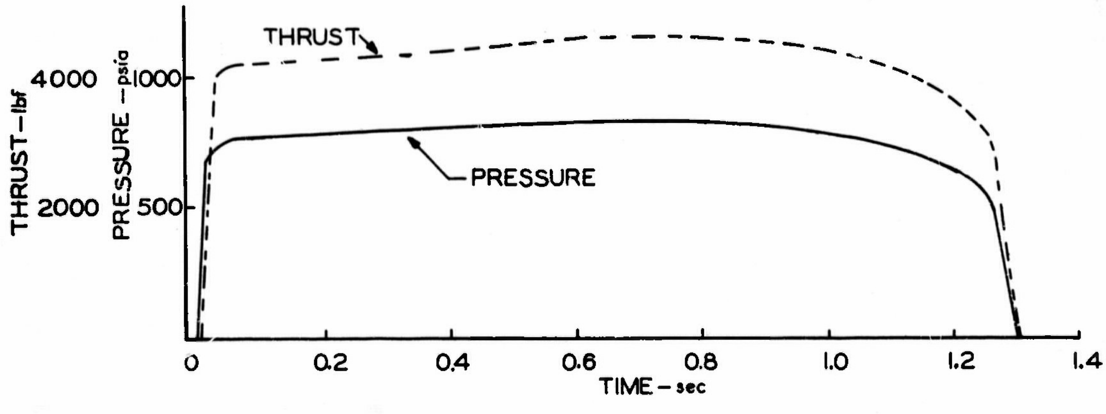


FIG. 8 PRESSURE- AND THRUST-TIME TRACES FROM APPLICATION MOTOR FIRING.

Table XV

Ballistic Data from Firing of 6ST18 Motor

	Round 4397	Round 4629	Round 4545
Propellant	RH-SB-103	RH-SB-103	RH-P-112
Grain Weight, lbm	22.22	22.28	20.45
Mean K	68	68	166
Burning Time (t_b), sec.	1.26	1.24	2.40
Burning Pressure ($\overline{P}_b$), psia	806	823	926
Burning Rate ($\overline{r}_b$), in/sec	1.12	1.18	0.59
Action Pressure ($\overline{P}_a$), psia	796	808	914
Action Time (t_a), sec.	1.29	1.28	2.46
$\int Pdt_b / \int Pdt_t$	0.99	0.98	0.99
Average Thrust, lbf	4230	4260	1913
I_{spd}, lbf-sec/lbm	248.6	248.8	232.7
F^0_{1000}, lbf-sec/lbm	258.1	257.7	238.6

Table XVI

Comparison of 6ST18 and 6C5-11.4 Results

Propellant	F^0_{1000} in 6ST18 (lbf-sec/lbm)	F^0_{1000} in 6C5-11.4 (lbf-sec/lbm)
RH-SB-103	257.9	262.8
RH-P-112	238.6	244.0

advantages of high burning rate, high density, and high specific impulse, the absence of a pressure exponent change with NF propellants allows much greater design freedom than is available with most composites.

The TOW launch motor specifications were taken as the basis of a demonstration. A motor designed for this application based on NF propellants had a slotted-tube grain, while one based on lower-energy, slower-burning propellants required a thin-webbed wagonwheel.[1] A comparison of the NF design with a plastisol nitrocellulose design showed a striking reduction in grain complexity, propellant mass, and loading fraction (Fig. 9).

A limited experimental effort was carried out to verify the practicability of this application. The propellant used, RH-SB-182ci,[2] contains 1% aluminum and 8μ ammonium perchlorate; the I^0_{sps} value is 265.4 lbf-sec/lbm and the theoretical density is 0.063 lbm/in^3.

CONVENTIONAL PROPELLANT NF PROPELLANT

PARAMETER	CONVENTIONAL	NF
TOTAL IMPULSE	280	280
SPECIFIC IMPULSE	200	226
PROPELLANT MASS (lbs)	1.46	1.25
LOADING FRACTION (%)	54	41
BURNING RATE (in/sec.)	2.0	6.25
OPERATING PRESSURE LIMIT (psia)	4000	> 10000

FIG. 9 POSSIBLE PROPELLANT CHARGE DESIGNS FOR TOW LAUNCH MOTOR.

[1] Rohm & Haas Company, "Demonstration of the Use of Composite Plastisol Nitrocellulose Propellant in a Short-Burning Rocket" (U) Special Report S-55, January 1965.

[2] The formulation of RH-SB-182ci is

NFPA	-	11.0%
TVOPA	-	33.0%
APC	-	55.0%
Al	-	1.0%

Four full-scale motors with the slotted-tube grain were fired at temperatures from -25° F to +125° F; the results of the firings were encouraging. The total impulse and action time specifications were met (Table XVII, Fig. 10).

Table XVII

Firings of RH-SB-182ci in SS Configuration

Round No.	T, °F	Propellant Mass, (lbm)	K_m	$\overline{P}_b$ (psia)	$\overline{P}_a$ (psia)	$\overline{r}_b$ (in/sec)	t_b (msec)	t_a (msec)	$\int F dt$ (lbf-sec)	I_{spd} (lbf-sec/lbm)	F^0_{1000}, (lbf-sec/lbm)
4696	+88	1.18	84.8	4680	4060	5.42	43.2	52.8	282.8	238.1	262.5
4715	-25	1.20	----	a	5530	----	a	47.0	287 0	240.0	259.9
4756	-25	1.19	98.6	6590	5200	6.79	34.6	47.8	284.7	239.3	257.8
4796	+125	1.19	83.4	5750	4760	7.43	30.8	44.6	283.3	238.9	261.3

[a]Instrumentation failure.

These data were corrected to a constant K value to give a better indication of the effect of temperature on motor performance (Table XVIII).

If the motors were fired at a K_m of 96, $(\overline{P}_b)_{+125}$ would be only 37% greater than $(\overline{P}_b)_{-25}$. This compares very favorably with the double-base round in which $(\overline{P}_b)_{+125}$ is about twice as great as $(\overline{P}_b)_{-25}$. Some improvement in ignition should be possible and could allow a reduction in design pressure of as much as 5 to 7%.

The movies of the firings indicated that the magnesium/KNO_3/$Ba(NO_3)_2$ igniter produced more flash and smoke than did the propellant.

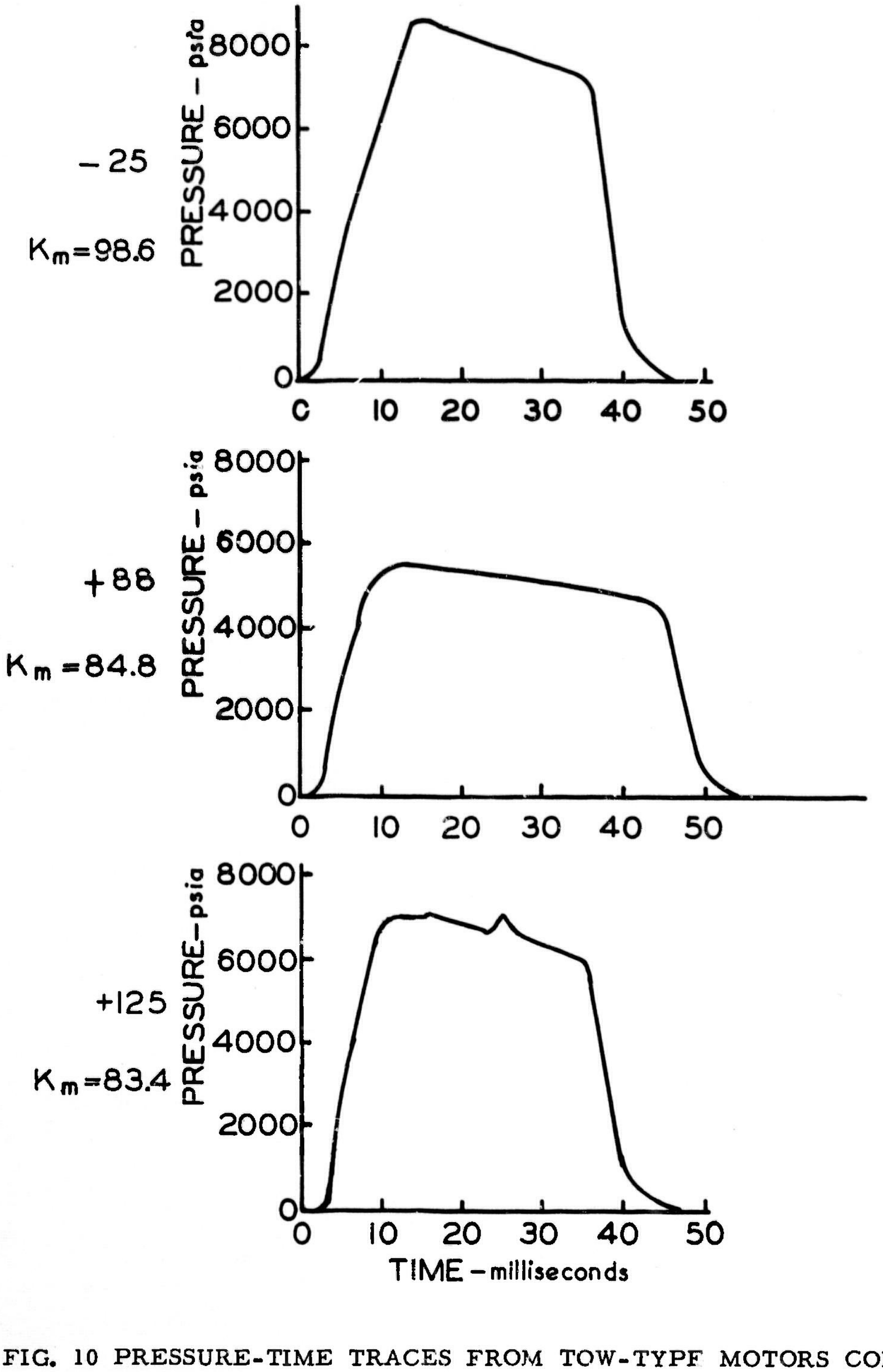


FIG. 10 PRESSURE-TIME TRACES FROM TOW-TYPF MOTORS CONTAINING RH-SB-182ci.

Table XVIII

Effect of Temperature on Launch Motor Performance

(K_m Corrected to 96)

Temp., °F	$\bar{P}_b$ (psia)	$\bar{r}_b$ (in/sec)	t_b (msec)	t_a (msec)
-25	5800	6.2	37.9	50.9
+88	6400	6.8	34.4	44.0
+125	8000	8.6	26.6	40.2

6. CHARACTERISTICS OF NF PROPELLANTS WITH A HIGHER ENERGY PLASTICIZER

6.1 OPE Formulations

A plasticizer having a higher energy level than TVOPA has been synthesized in hundred-gram quantities. This material, 1, 2, 2, 5, 6, 9, 9, 10-octakis(difluoramino)-4, 7 dioxadecane (code-named OPE), is more sensitive than TVOPA, but makes I^0_{sps} values in the 274-275 lbf-sec/lbm range possible. The ballistic properties of several OPE/NFPA propellants were studied (Table XIX).

Table XIX

High-Energy NF Formulations Containing OPE

Component	RH-SB-153	RH-SB-164	RH-SB-174	RH-SB-180
NFPA	15.0	13.0	12.5	16.6
OPE	45.0	26.0	37.5	33.4
Ammonium Perchlorate	33.7	46.0	40.3	40.7
Aluminum	6.3	15.0	9.7	9.3
I^0_{sps}	276.8	273.5	276.7	275.4

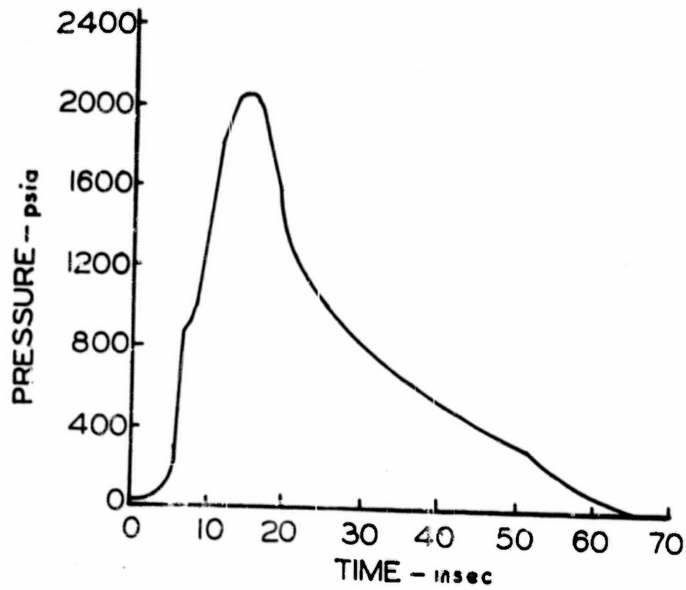
6.1.1. Burning Rate Behavior

The burning rates of OPE formulations were obtained in 0.75C0.50-1.5 micro-motors containing about 10 grams of propellant. The pressure-time traces were erratic at times owing to the fact that the bond to the steel case was weaker than that of a TVOPA analog (Fig. 11a), and also because the pressure exponents of some of the propellants approached unity. The normal 9% hump in the surface-web curve for the micro-motor was magnified by the 0.9 pressure exponent into a 100% hump in the pressure-time trace (Fig. 11b). RH-SB-180ci, which had the lowest pressure exponent of this group, gave the best ballistic records (Fig. 11c).

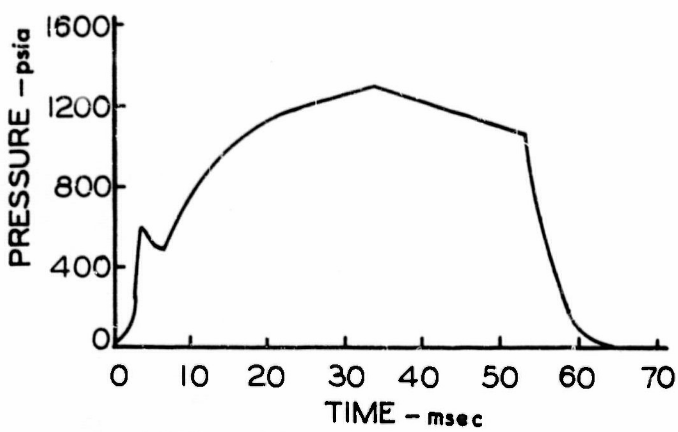
Even though the propellants were extremely sensitive to nozzle size, usable data were obtained from this series of firings. The burning rates were the highest yet obtained in the NF program; RH-SB-153 with 8μ oxidizer burned at 3.3 inches/second at 1000 psia. All of the propellants burned very fast, and all had pressure exponents between 0.7 and 0.9 (Table XX, Figs. 12 and 13).

6.1.2 Specific Impulse Evaluation

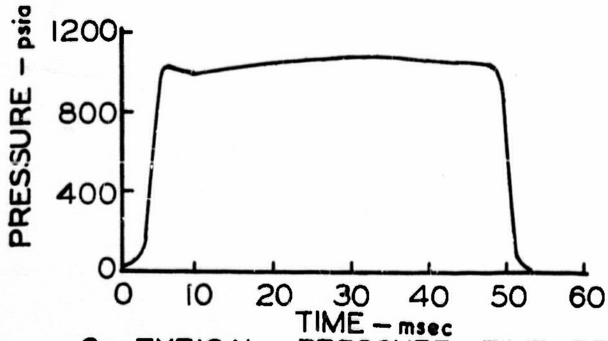
I^{0}_{sps} for RH-SB-180 and RH-SB-164 were not as high as those for RH-SB-153 and RH-SB-174, but the ballistic results were much more reproducible for the lower-energy propellants. Impulse evaluation for OPE propellants was done in 0.75C0.50-1.5 micro-motors containing RH-SB-164 and RH-SB-180. Both gave specific impulse values above 260 lbf-sec/lbm in the 1.5-inch long micro-motor (Table XXI). These are the highest F^{0}_{1000} values measured in this size motor to date.



A. TYPICAL CASE-BOND FAILURE



B. GOOD TRACE FROM PROPELLANT HAVING n=0.9



C. TYPICAL PRESSURE-TIME TRACE FROM RH-SB-180ci IN MICROMOTOR

FIG. 11 PRESSURE-TIME TRACES FROM MICRO-MOTORS CONTAINING OPE PROPELLANTS.

Table XX

Ballistic Data for OPE Propellants

(1.5-inch long micro-motors)

Propellant	Round No.	K_m	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\overline{P}_{eq.}$ (psia)
RH-SB-153cb	4184	30.7	413	1.32	415
	4188	31.3	421	1.90	426
	4185	33.7	843	2.44	861
	4186	34.2	1076	3.01	1103
	4189	35.5	1666	4.40	1726
	4187	36.4	1846	4.94	1935
RH-SB-153ci	4198	25.2	591	2.14	597
	4197	27.6	777	2.55	770
	4196	28.8	884	2.87	889
	4199	30.5	1176	3.59	1203
	4195	30.5	1257	4.10	1295
	4194	31.8	1361	4.17	1402
RH-SB-174cb	4170	28.9	335	1.07	334
	4172	30.5	447	1.42	455
	4175	31.7	400	1.29	405
	4174	32.4	694	2.00	----
	4176	32.4	663	1.92	687
	4181	33.4	819	2.46	848
	4179	33.8	977	2.98	----
	4177	33.9	1124	3.17	----
	4180	33.9	1146	3.17	1180
	4178	34.0	1054	2.87	----
	4171	34.4	897	2.48	920
	4168	34.5	1127	3.31	1166
	4173	36.4	1638	4.37	1745
RH-SB-180ci	4443	27.2	338	1.20	336
	4440	28.4	543	1.75	548
	4438	29.8	620	1.88	638
	4439	32.8	824	2.33	838
	4441	34.5	964	2.58	984
	4673	34.5	1050	2.90	1069
	4442	36.5	1187	2.95	1218
	4471	37.3	1199	3.00	1249
	4674	43.3	2548	5.17	2631
	4672	54.2	3898	8.17	----

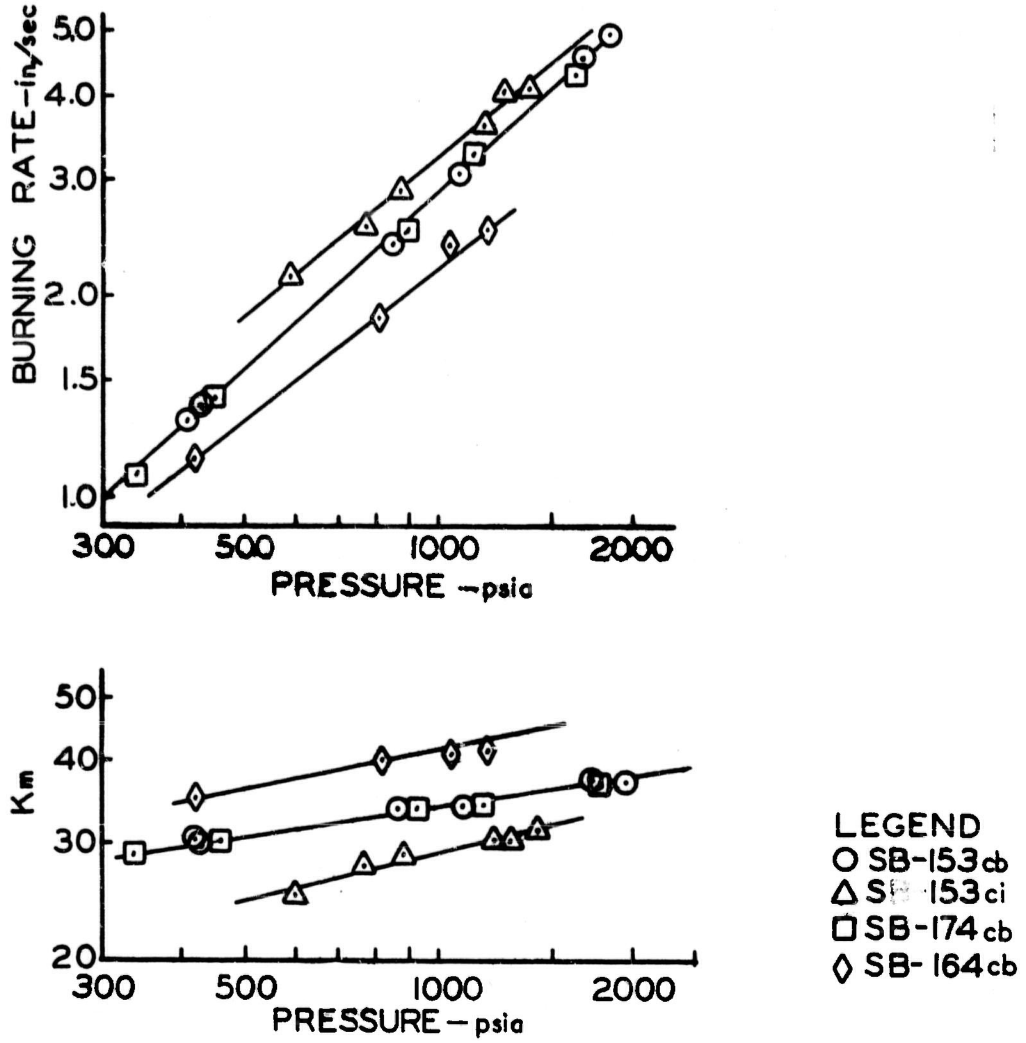


FIG. 12 P-K-r RELATIONSHIPS FOR OPE PROPELLANTS.

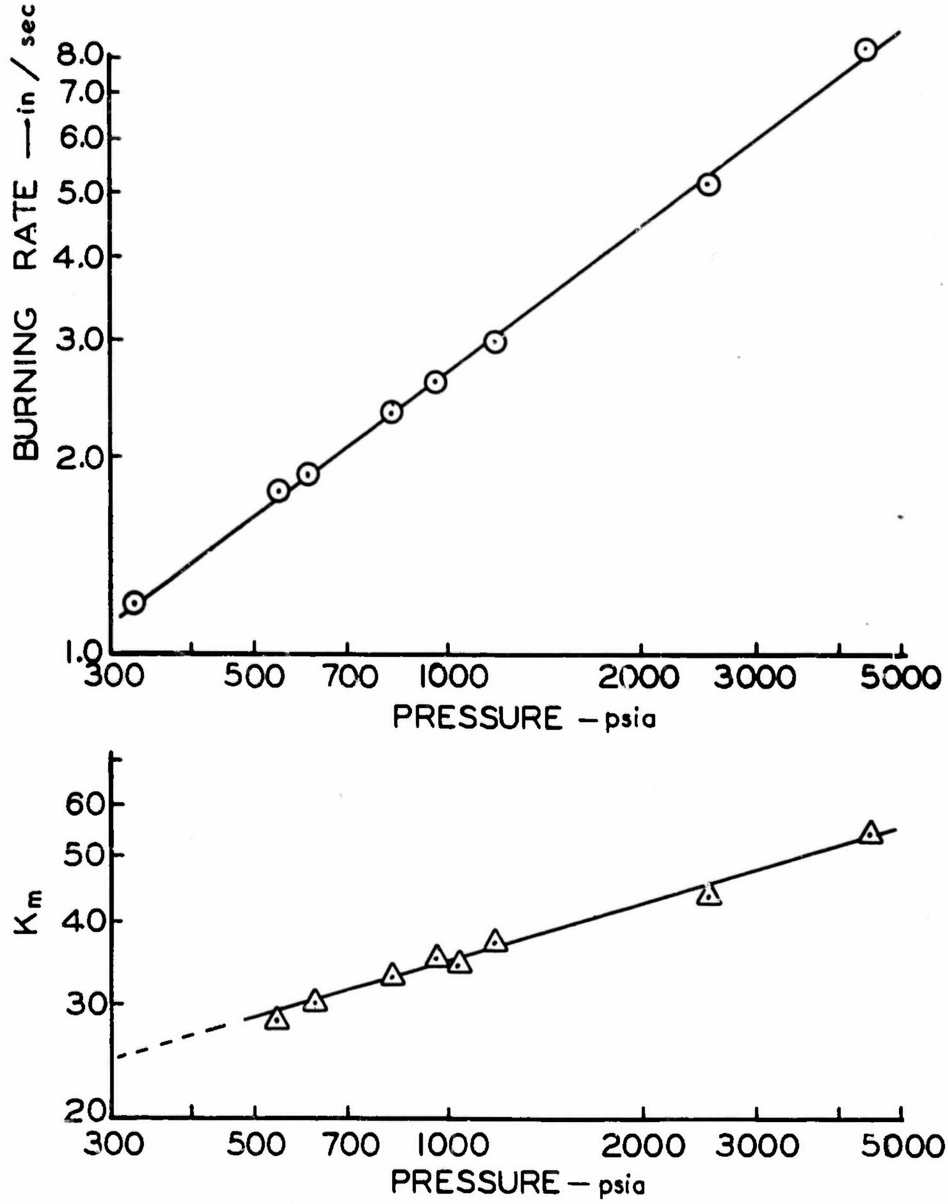


FIG. 13 BURNING RATE DATA FOR RH-SB-180ci.

Table XXI

Impulse Data from Selected OPE Propellants Obtained in 0.75C0.50-1.5 Micro-Motors

Propellant	Round No.	K_m	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\overline{P}_{eq.}$ (psia)	F^0_{1000} (lbf-sec/lbm)
RH-SB-164cb	4431	35.0	419	1.13	400	
	4435	39.5	800	1.84	844	260.1
	4434	41.2	1192	2.50	1240	260.4
	4436	41.2	1084	2.45	1129	260.0
	4433	41.4	1090	2.35	1131	261.8
	4432	42.0	1050	2.39	1081	258.9
					Average	260.2
RH-SB-180ci	4449	36.1	1021	2.54	1064	261.7
	4444	35.7	1034	2.55	1056	260.1
	4446	35.8	987	2.49	1024	259.4
	4857	35.6	1053	2.65	1146	258.9
	4858	35.6	1041	2.65	1103	261.3
	4859	35.7	1068	2.65	1239	258.4
	4860	35.6	1054	2.66	1172	262.7
	4861	35.5	1025	2.57	1127	263.1
	4866	35.0	913	2.40	976	262.2
					Average	260.9

7. SUMMARY

NFPA-TVOPA propellants are well-behaved and have ballistic properties that will be usable in several different applications. Most notable are their high specific impulse and good combustion efficiency over a wide range of aluminum content. In the 2-inch test motor, RH-SB-103cb (15% aluminum) produces a corrected specific impulse of 257 lbf-sec/lbm. The 1% and 25% aluminum compositions give corrected values of 253 and 250 lbf-sec/lbm, respectively. A density-impulse product of 17.26 lbf-sec/in^3 was demonstrated in 2-inch test motors. In 100 lbm motors, a density impulse product of 17.70 lbf-sec/in^3 is predicted. As with other composite propellants, oxidizer particle size has a substantial effect on burning rate and a range of 0.83 to 1.90 in/sec was achieved for RH-SB-103; the variation was reasonable and reproducible. In contrast, the aluminum content has very little effect on the burning rate of balanced compositions.

The NF propellants have a reasonable pressure exponent in the burning rate equation. At 1000 psia, the value ranges from 0.56 to 0.63. A break-point occurs at 1500-2000 psia for propellants having oxidizer with a mean particle diameter above 43 microns. However, there is no break-point up to 5000 psia with 15 and 8 micron ammonium perchlorate.

The π_K of RH-SB-103 is 0.11%/°F over the temperature range -40°F to +140°F.

An interim liner based on a polyester-asbestos material has given good results.

Evaluation of RH-SB-103 has been continued in 6-inch motor hardware containing a 22-lbm slotted-tube charge. The two firings were successful and the ballistic results were very reproducible. The use of NF propellants in the very high pressure regime (7500 psia) was demonstrated in the successful firing of 2-inch motors designed to meet specifications of the ejector for a tube-launched missile. Very little flash or smoke was observed in the movies of these firings.

Some work was done with higher energy NF plasticizers. The OPE-containing propellants tested had F^0_{1000} values of over 260 lbf-sec/lbm in 1.5-inch long motors and burning rates as high as 3.3 in/sec at 1000 psia were measured.

8. PLANNED EXTENSIONS

The work discussed in this report has suggested several interesting and important avenues for future investigation. Some of these which are currently being followed or which soon will be are listed below:

1. Development of scaling factors for RH-SB-184, RH-SB-103, and RH-SB-188.

2. Further scale-up to an eighty-pound grain in the 5KS-4500 motor case.

3. Study of NF formulations without aluminum to determine whether combustion instability occurs.

4. Determination of the toxic properties of the exhaust.

5. Determination of signature (smoke, flash) of exhaust from low-aluminum propellant exhaust.

6. Continuation of study of the very high-rate propellants using OPE plasticizer.

7. Confirmation of cause of the low impulse value measured in the 6ST18.

APPENDIX A

LINER BONDING TESTS

Case-bonding studies for NFPA propellant have been carried out with bond jigs which contain approximately ten grams of propellant and test 0.25 in^2 of surface area. These test vehicles consist of a cylindrical top-piece and a flat surface base which are separated with a Teflon®[1] washer (Fig. A-1).

The various liner formulations are applied to the base plate inside the Teflon washer and cured. The inside diameter of the washer is sized to allow 0.25 in^2 of liner surface area to be tested. The cylindrical top-piece is assembled with the base and propellant is cast onto the liner sample. The propellant/liner bond is tested by separating the jig. Maximum stress is recorded and the propellant/liner interface is visually inspected to determine the type of failure.

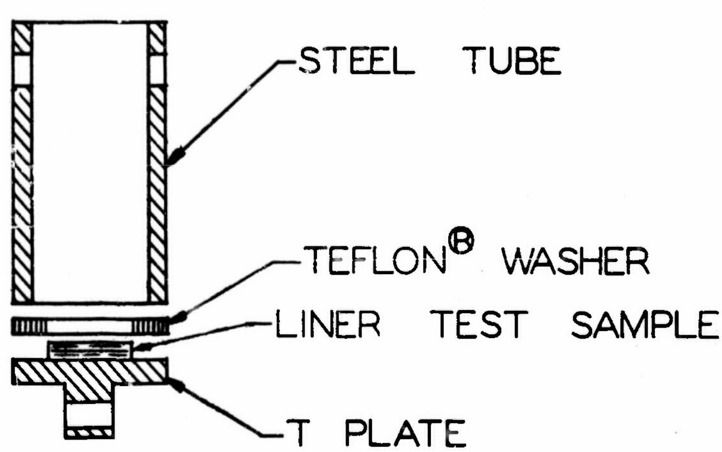


FIG. A-1 CASE-BOND JIG ASSEMBLY.

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[1]Trademark for tetrafluoroethylene (TFE) fluorocarbon resins, E. I. duPont de Nemours & Co., Inc., Wilmington 98, Del.

APPENDIX B

GLOSSARY

A-10	Acryloid® acrylic resin (Rohm & Haas Company, Philadelphia, Pa.).
AT-50	Acryloid® acrylic resin (Rohm & Haas Company, Philadelphia, Pa.).
A-L-100	Adiprene® L-100 polyurethane (E. I. duPont de Nemours & Co., Inc., Wilmington, Del.).
B-10	Rhoplex® acrylic emulsion (Rohm & Haas Company, Philadelphia, Pa.).
D-65	Polyurethane thermal coating (Dyna-Therm Chemical Corp.,Culver City, Calif.).
D-65-A	Primer for polyurethane coatings (Dyna-Therm Chemical Corp.,Culver City, Calif.).
D-904	Polyurethane top-coat (Dyna-Therm Chemical Corp., Culver City,Calif.).
E-15	Ethyl phthalyl ethyl glycolate (Monsanto Chemical Co., St. Louis, Mo.).
E-53-L	Eponol® epoxy base surface coating (Shell Chemical Co., New York, N. Y.).
E-55	Eponol® epoxy base surface coating (Shell Chemical Co., New York, N. Y.).
E-828	Epon® epoxy resin (Shell Chemical Co., New York, N. Y.).
ER-504	Epi-Rez® epoxy resin (Jones-Dabney Co., Louisville, Ky.).
F-700	Flamastic® flame-resistant coating compound (Dyna-Therm Chemical Corp.,Culver City, Calif.).
HA-12	Rhoplex® acrylic emulsion (Rohm & Haas Company, Philadelphia, Pa.).
K-120-N	Powdered poly(methylmethacrylate)(Rohm & Haas Company, Philadelphia, Pa.).
P-13	Paraplex® polyester resin (Rohm & Haas Company Philadelphia, Pa.).

P-43	Paraplex® polyester resin (Rohm & Haas Company, Philadelphia, Pa.).
PL-1	Cellulose acetate lacquer.
Plexiglas®	Sheet poly(methylmethacrylate) (Rohm & Haas Company, Philadelphia, Pa.).
42 RPD®	Phenolic impregnated asbestos (Raybestos-Manhattan, Manheim, Pa.).
Santicizer®-160	Butyl benzyl phthalate (Monsanto Chemical Co., St. Louis, Mo.).

APPENDIX C

TABLE OF NOMENCLATURE

D^{50}_{M}	=	Weight-average mean particle size, microns.
F	=	Thrust.
F^{0}_{1000}	=	Specific impulse corrected to 1000 psia chamber pressure, optimum expansion ratio at sea level atmospheric pressure (14.7 psia) and 0° nozzle exit divergence angle.
I_{spd}	=	Delivered specific impulse.
I^{0}_{sps}	=	Theoretical specific impulse at 1000 psia chamber pressure, optimum expansion ratio at sea level atmospheric pressure (14.7 psia), and 0° nozzle exit divergence angle.
K_m	=	$S_m/\overline{A}_t$, where S_m is an integral average surface area and $\overline{A}_t$ is the arithmetic average of throat area before and after firing.
μ	=	Micron.
$\overline{P}_a$	=	Average pressure over the action time.
$\overline{P}_b$	=	Average pressure over burning time.
$\overline{P}_{eq}$		Equilibrium pressure, defined as integral average pressure from time where chamber pressure is fully established to t_b. Tangents are drawn to determine beginning and ending points of equilibrium time.
π_K	=	Temperature coefficient based on pressure $\frac{\partial(\ln P)}{\partial T}$.
$\overline{r}_b$	=	Average burning rate over the burning time.
t_a	=	Action burning time.
t_b	=	Web burning time.